Enhancing athletic performance through high-intensity interval training and sodium bicarbonate supplementation

UNIVERSITY OF TASMANIA

Matthew W. Driller

B.Sp.Ex.Sci (Hons)

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

School of Human Life Sciences, University of Tasmania, Australia.

February 2012

Primary Supervisor: Dr. James Fell

Statement of Originality and Ethical Conduct

I, Matthew Driller certify that this work is entirely my own effort except where otherwise acknowledged. I also certify that, to the best of my knowledge and belief, the work is original and has not been previously submitted for any other award, nor does the thesis contain any material that infringes copyright. This thesis may be made available for loan and limited copying in accordance with the Copyright Act 1968.

The research associated with this thesis abides by the international and Australian codes on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene Technology Regulator and the rulings of the Safety, Ethics and Institutional Biosafety Committees of the University.

Matthew Driller  Date: 27/02/2012

SUPERVISOR ENDORSEMENT  Date: 27/02/2012

Abstract

Introduction: Metabolic acidosis is a by-product of the energy production process required during high-intensity exercise, and it is thought to play a part in influencing muscle function and fatigue. Consequently, the efficacy of an athlete's intra- and extra-cellular buffering systems may influence their performance during an exercise task. These buffering systems can be enhanced through exercise training and nutritional supplementation. Therefore, the purpose of this series of studies was to investigate combined training and sodium bicarbonate ($NaHCO_3$) supplementation techniques for enhancing performance in well-trained athletes.

Study 1. The aim of this study was to evaluate high-intensity interval training (HIT) for improving performance in already well-trained athletes. To achieve this we compared traditional rowing training (CT) to HIT in state-representative rowers. Following baseline testing (2000 m rowing test, incremental rowing test) 10 rowers were randomly allocated to HIT or CT, which they performed seven times over a 4-week period, after post-treatment testing the rowers were allocated to the alternative training method, completing a cross-over design. The HIT produced significantly greater improvements in 2000 m time, 2000 m power and relative $\dot{V}O_{2\ peak}$ when compared to CT ($P < 0.05$). It was concluded that four weeks of HIT improves 2000 m time-trial performance and relative $\dot{V}O_{2\ peak}$ in competitive rowers, more than CT.

Study 2. After establishing that HIT was effective in improving rowing performance the next step was to investigate if the combination of HIT and $NaHCO_3$ supplementation could further enhance performance. However, the research literature was still equivocal as to the most effective method of $NaHCO_3$ supplementation. Consequently, the aim of Study 2 was

to compare acute $NaHCO_3$ loading with serial $NaHCO_3$ loading (split doses over three days) in well-trained cyclists to establish which method was best for producing performance improvements and enhanced acid-base balance with minimal side effects. Eight male cyclists completed three tests in a double blind, randomised design over a three week timeframe: acute $NaHCO_3$ loading (AL), serial $NaHCO_3$ loading (SL) and a placebo loading condition (P). Following each loading protocol, cyclists completed a 4-min performance test on a cycling ergometer. Both the AL and SL trials produced a significantly higher average power in the 4-min test when compared to the P trial ($P < 0.05$), with no significant difference between AL and SL trials ($P = 0.29$). The improvements in performance associated with the SL trial were despite any changes to the measure blood-gas variables (pH and HCO_3^-). It was concluded that SL may provide a convenient and practical alternative approach for athletes preparing for competition; however, AL was the most effective for altering acid-base balance as well as improving performance with minimal negative side-effects, and was deemed the most appropriate method to use when combing HIT and $NaHCO_3$.

Study 3. With appropriate protocols for both HIT and $NaHCO_3$ loading in well-trained athletes confirmed, the aim of Study 3 was to combine these two strategies and investigate whether there was any additive benefit when used in a chronic training setting. Subjects were 12 elite rowers preparing for international competition. Following baseline testing, rowers were allocated to either $NaHCO_3$ (ALK) or a placebo (PLA) group (sodium chloride matched for equimolar sodium content). Both groups performed 8 HIT sessions over a 4-week period. Prior to each HIT session, subjects were required to ingest $NaHCO_3$ or a placebo substance. The 2000 m time-trial performance improved after 4 weeks of HIT; however, there were no statistically significant performance improvements ($P > 0.05$)

attributable to the $NaHCO_3$ supplementation during HIT training of fixed volume and intensity.

Study 4. Due to the results from Study 2 and 3, along with some inconsistencies in the literature regarding the influence of $NaHCO_3$ loading on athletic performance, it was hypothesised that a possible reason for lack of performance improvements after $NaHCO_3$ supplementation was the use of sodium chloride (NaCl) as a placebo. The sodium content has been proposed to provide some performance benefits, possibly through blood volume shifts, obscuring some of the benefits associated with $NaHCO_3$ supplementation, limiting its use as a valid placebo substance. Therefore the aim of Study 4 was to compare $NaHCO_3$ and NaCl to a physically inert substance by evaluating the haematocrit changes and their influence on high-intensity cycling performance. Subjects undertook three tests in a random, double-blind design over a one week timeframe: $NaHCO_3$ loading (SB), NaCl loading (SC) and dextrose loading (D). Following each loading protocol, subjects completed a 2-min performance test on a cycling ergometer. The SB trial produced a significantly higher ($P < 0.01$) mean power (W) in the 2-min test when compared to the SC and D trial with no significant difference between SC and D trials ($P > 0.05$). It was concluded that the HCO_3^- not the Na^+ was primarily responsible for providing any ergogenic benefit during high-intensity exercise performance.

Conclusions: The findings from these studies suggest that independently, both HIT and $NaHCO_3$ supplementation can improve high-intensity exercise performance in well-trained athletes. However, this thesis provides the first study to investigate the combination of these two techniques in highly-trained athletes and provides evidence that such an approach does not lead to additional performance gains in this population; however, further research is warranted. The findings from the final study of the thesis suggest that it is the HCO_3^- content in $NaHCO_3$ which is likely to facilitate performance benefits more so than

the Na^+ content. The findings of the studies included in this thesis are applicable to high-intensity exercise performance in the context of high-level athletic competition. The research adds to the knowledge base regarding practical information for athletes and coaches in terms of novel $NaHCO_3$ loading and interval training protocols while providing likely performance outcomes.

Publications Arising From This Thesis

- **Driller, M**., Fell, J., Gregory, J., Shing, C. and Williams, A. (2009). The effects of high-intensity interval training in well-trained rowers. *International Journal of Sports Physiology and Performance*, 4 (1).

- **Driller, M**., Gregory, J., Williams, A. and Fell, J (2012). The effects of serial and acute $NaHCO_3$ loading in well-trained cyclists. *Journal of Strength and Conditioning Research*, (Published Ahead of Print).

- **Driller, M**., Williams, A., Bellinger, P., Howe, S. and Fell, J. (2012). The effects of $NaHCO_3$ and NaCl loading on haematocrit and high-intensity cycling performance. *Journal of Exercise Physiology (online),* 15 (1).

- **Driller, M**., Gregory, J., Williams, A. and Fell, J. The effects of chronic sodium bicarbonate loading and interval training in highly-trained rowers. Under review – *International Journal of Sports Nutrition and Exercise Metabolism.*

- Shing, C, **Driller, M**, Williams, A, Webb, J and Fell, J. The effects of high-intensity interval training on plasma adiponectin in well-trained rowers. Under review - *Journal of Strength and Conditioning Research.*

Peer Reviewed Conference Proceedings

- **Driller, M**., Fell, J., Gregory, J., Shing, C. and Williams, A. (2008). The effects of high-intensity interval training in well-trained rowers. Australian Association for Exercise and Sports Science. Melbourne, Australia.

- **Driller, M**., Fell, J., Gregory, J., Shing, C. and Williams, A. (2008). The effects of high-intensity interval training in well-trained rowers. National Elite Sports Council Forum. Canberra, Australia.

- **Driller, M**., Gregory, J., Williams, A. and Fell, J. (2009). The effects of serial vs acute $NaHCO_3$ loading in highly-trained cyclists. Sports Medicine and Science. Rotorua, New Zealand.

- **Driller, M**., Gregory, J., Williams, A. and Fell, J. (2010). The effects of serial vs acute $NaHCO_3$ loading in highly-trained cyclists. Exercise and Sports Science Australia. Gold Coast, Australia.

- **Driller, M.**, Gregory, J., Williams, A. and Fell, J. (2010). The effects of chronic sodium bicarbonate loading and interval training in highly-trained rowers. National Elite Sports Council Forum. Canberra, Australia.

Awards/Grants

- Australian Association for Exercise and Sports Science Young Investigator Award. Melbourne, Australia. **Driller, M**., Fell, J., Gregory, J., Shing, C. and Williams, A. (2008). The effects of high-intensity interval training in well-trained rowers.

- Australian Institute of Sport (AIS) Collaborative Research Grant (2008-2009).

Statement of Candidate Contribution

This thesis comprises four research investigations which have been completed almost entirely by Matthew Driller (the candidate). The candidate designed the studies, coordinated and supervised all data collection, analysed the data, and prepared all manuscripts. The contributions of all parties to each of the four studies are detailed below.

Study one: The effects of high-intensity interval training in well-trained rowers

- Mr Matthew Driller: lead role in study design, data collection, statistical analysis and first author on manuscript (70%)
- Dr James Fell: assisted with study design, data collection and manuscript revision (20%)
- Dr Andrew Williams: assisted with study design, data collection, statistical analysis and manuscript revision (5%)
- Mr John Gregory: assisted with data collection (2.5%)
- Dr Cecilia Shing: assisted with data collection and manuscript revision (2.5%)

Study two: The effects of serial and acute $NaHCO_3$ loading in well-trained cyclists

- Mr Matthew Driller: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr James Fell: assisted with study design and manuscript revision (10%)
- Mr John Gregory: assisted with data collection (5%)
- Dr Andrew Williams: assisted with statistical analysis and manuscript revision (5%)

Study three: The effects of chronic sodium bicarbonate loading and interval training in highly-trained rowers

- Mr Matthew Driller: lead role in study design, data collection, statistical analysis and first author on manuscript (80%)
- Dr James Fell: assisted with study design, statistical analysis and manuscript revision (10%)
- Mr John Gregory: assisted with data collection (5%)
- Dr Andrew Williams: assisted with statistical analysis (5%)

Study four: The effects of $NaHCO_3$ and NaCl loading on performance

- Mr Matthew Driller: lead role in study design, data collection, statistical analysis and first author on manuscript (65%)
- Dr James Fell: assisted with study design, statistical analysis and manuscript revision (10%)
- Mr Sam Howe: assisted with data collection and manuscript revision (10%)
- Mr Phillip Bellinger: assisted with data collection and manuscript revision (10%)
- Dr Andrew Williams: assisted with statistical analysis and manuscript revision (5%)

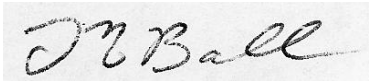
There was one further study that was directly related to this thesis and it appears in the appendices (Appendix I). The study was derived from blood collected during the conduct of study one. Therefore, the candidate completed all data collection but did not perform the first draft of the final manuscript and as such has not been included as part of the body of the thesis. The contribution to the study is listed below:

Study five: The effects of high-intensity interval training on plasma adiponectin in well-trained rowers

- Dr Cecilia Shing: data collection, statistical analysis and first author (40%)
- Mr Matthew Driller: assisted with data collection and manuscript revision (30%)
- Dr James Fell: assisted with data collection and manuscript revision (15%)
- Ms Jess Webb: assisted with data collection, analysis of blood, and manuscript revision (10%)
- Dr Andrew Williams: assisted with data collection and manuscript revision (5%)

We the undersigned agree with the above stated "proportion of work undertaken" for each of the above published (or submitted) peer-reviewed manuscripts contributing to this thesis:

Signed: Candidate _____



Signed: _____ _____

Dr. James Fell
Supervisor
School Of Human Life Sciences
University of Tasmania

Professor Madeleine Ball
Head of School
School of Human Life Sciences
University of Tasmania

Date: 27/02/2012

Acknowledgements

Firstly, I would like to thank all of the athletes (and their coaches) who have taken part in all of my studies, without you, this would not have been possible. It was a pleasure working with so many driven individuals who were always willing to give 100% in each test they completed. I have gained a new level of respect for the level of dedication and sacrifice involved in being a top-class athlete. Good luck to all the subjects from my studies as you strive to reach your goals, especially those who are competing in the London Olympics this year. I feel very lucky to work in an area that I am passionate about and look forward to going to work every day. With this, I would like to acknowledge my current employer, the Australian Institute of Sport (AIS). It is an honour to work in such an elite environment and be surrounded by so many experts in their field. Thank you for allowing me to continue work on my PhD while being employed full-time.

To my primary supervisor, James – what a ride! Thank you for taking a risk and giving the scholarship position to a Kiwi. Thank you for your brilliant supervision and for always making time for me no matter how busy you are. I have learnt so much over the last 5 years and I am lucky to have had a supervisor with so many different areas of expertise. I really appreciate the opportunities and experience that you offered me in Tassie, and for making the transition over the ditch an easy one. Thank you also for your patience, perseverance, humour and understanding throughout my PhD. I look forward to our collaborations in the future!

To my other University supervisors, Andrew Williams and Cecilia Shing - thank you for your invaluable input into my PhD candidature, and the great amounts of time you have

made available to read and discuss my work. Ceils – thanks for giving me the opportunity to be involved with your research and teaching at uni and for the insight you provided to my studies. Andy – thanks for sharing your expertise in statistical analysis and for the revisions of my manuscripts and thesis.

To my practical supervisor, John Gregory, and all the staff at the Tasmanian Institute of Sport – I am very appreciative of the experiences in applied sport science I have gained while completing my PhD with you. It was fantastic being able to complete my PhD while, at the same time, gaining experience working with some of Australia's top athletes. Thank you, John, for your support in helping me find subjects for my studies and for teaching me all the practical skills required for testing athletes over a range of sports. Your passion for helping athletes improve is infectious.

I would like to acknowledge Dr Johann Edge. Johann's work provided the inspiration for some of the studies in this thesis. Johann was kind enough to provide me with advice when I was designing some of my studies. Unfortunately, in March 2010, Johann passed away in a cycling accident. I feel honoured to have known him and privileged that I could carry on some of the work he started.

To my parents, thank you for supporting me in pursuing my career in sports physiology, even if you didn't know there was such a thing and would prefer I got a "real job". Thank you also for instilling in me the importance of hard work.

Lastly, I would like to thank my wife, Kirsty. It’s been a trying journey over the last 5 years - but we made it! Thank you for encouraging me to finish this thing and for letting me follow my dreams. Hopefully, we can now spend some more weekends together!

Table of Contents

Statement of Originality and Ethical Conduct ii
Abstract iii
Publications Arising From This Thesis vii
Peer Reviewed Conference Proceedings viii
Awards/Grants ix
Statement of Candidate Contribution x
Acknowledgements xiii
List of Tables 4
List of Figures 5
Abbreviations 6
Overview 8
Thesis Organisation 11
Chapter One: 15
Introduction 15
General Introduction 16
Importance of muscle buffer capacity 19
Muscle buffer capacity in response to exercise 22
Extracellular buffering 23
Summary 23
Chapter Two: 25
Literature Review: 25
PART A - The effect of high-intensity interval training on physiology and performance 25
High-intensity interval training (HIT) 26
Physiological rationale for HIT 27
Peripheral adaptations to HIT 27
HIT induced changes to muscle buffer capacity 27
Other peripheral adaptations to HIT 31
Central adaptations to HIT 33
The influence of HIT in trained and untrained populations 36
Untrained 36
Trained 37
Summary 40
PART B - The effect of $NaHCO_3$ supplementation on physiology and performance 41
Background 42
Physiology of $NaHCO_3$ supplementation 43

$NaHCO_3$ and Exercise Performance 45
$NaHCO_3$ dosing and loading regimens 53
Acute $NaHCO_3$ loading 53
Serial $NaHCO_3$ loading 55
Chronic $NaHCO_3$ loading 57
Effects on blood variables 58
Gastro-intestinal side effects 61
Summary 64
Literature Review: Conclusion 65
Chapter Three: 68
The effects of high-intensity interval training in well-trained rowers 68
Abstract 69
Introduction 70
Methods 71
Results 80
Discussion 84
Practical Applications 87
Conclusion 87
Chapter Four: 89
The effects of serial and acute $NaHCO_3$ loading in well-trained cyclists 89
Abstract 90
Introduction 91
Methods 94
Results 99
Discussion 104
Practical Applications 107
Chapter Five: 108
The effects of chronic sodium bicarbonate ingestion and interval training in highly-trained rowers 108
Abstract 109
Introduction 110
Methods 112
Results 118
Discussion 122
Conclusion 126

Chapter Six: 127
The effects of $NaHCO_3$ and NaCl loading on haematocrit and high-intensity cycling performance 127
Abstract 128
Introduction 129
Methods 131
Results 135
Discussion 140
Conclusions 143
Chapter Seven: 145
Thesis Summary 145
Limitations 153
Practical Applications 155
Future Directions 159
REFERENCES 161
APPENDICES 175
APPENDIX I: 175
Circulating adiponectin concentration is altered in response to high-intensity interval training 175
APPENDIX II: 195
Participant Information Sheets and Informed Consent 195
APPENDIX III: 214
Questionnaires 214
APPENDIX IV: 222
Diaries 222